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(54) **INTEGRATED ILLUMINATION ASSEMBLY
FOR SYMBOLOGY READER**

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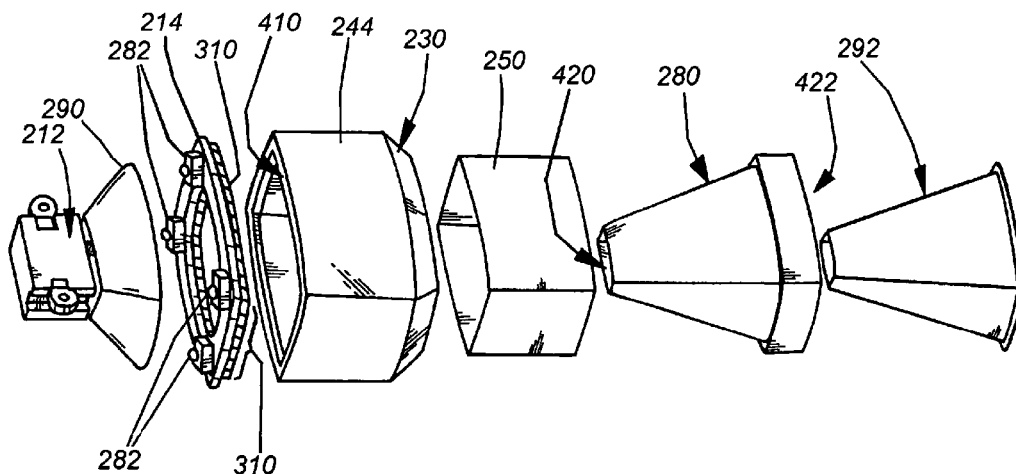
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(57) **ABSTRACT**

A light transmitter (e.g., pipe) is constructed from polycarbonate for increased shock resistance and can define a rectangular cross section. A chamfered end of the light pipe is textured or frosted to further diffuse refracted light passing through the end to present a more even effect. A conical/tapered diffuser within the light pipe is illuminated by a reflector that reflects a plurality of rear-ward-directed illumination sources back into the diffuser. The reflector can direct light into the forwardmost, remote regions of the diffuser to generate a better spread of light and alleviate spotting effects. The illumination sources can be multi-colored sources that respond to a controller to project a color and/or blink in a pattern to indicate various conditions. The controller can operate individual portions of the ring so that only corresponding portions of the light pipe perimeter are illuminated in a particular color at a given time. Different quadrants may be simultaneously illuminated in different colors.

28 Claims, 17 Drawing Sheets



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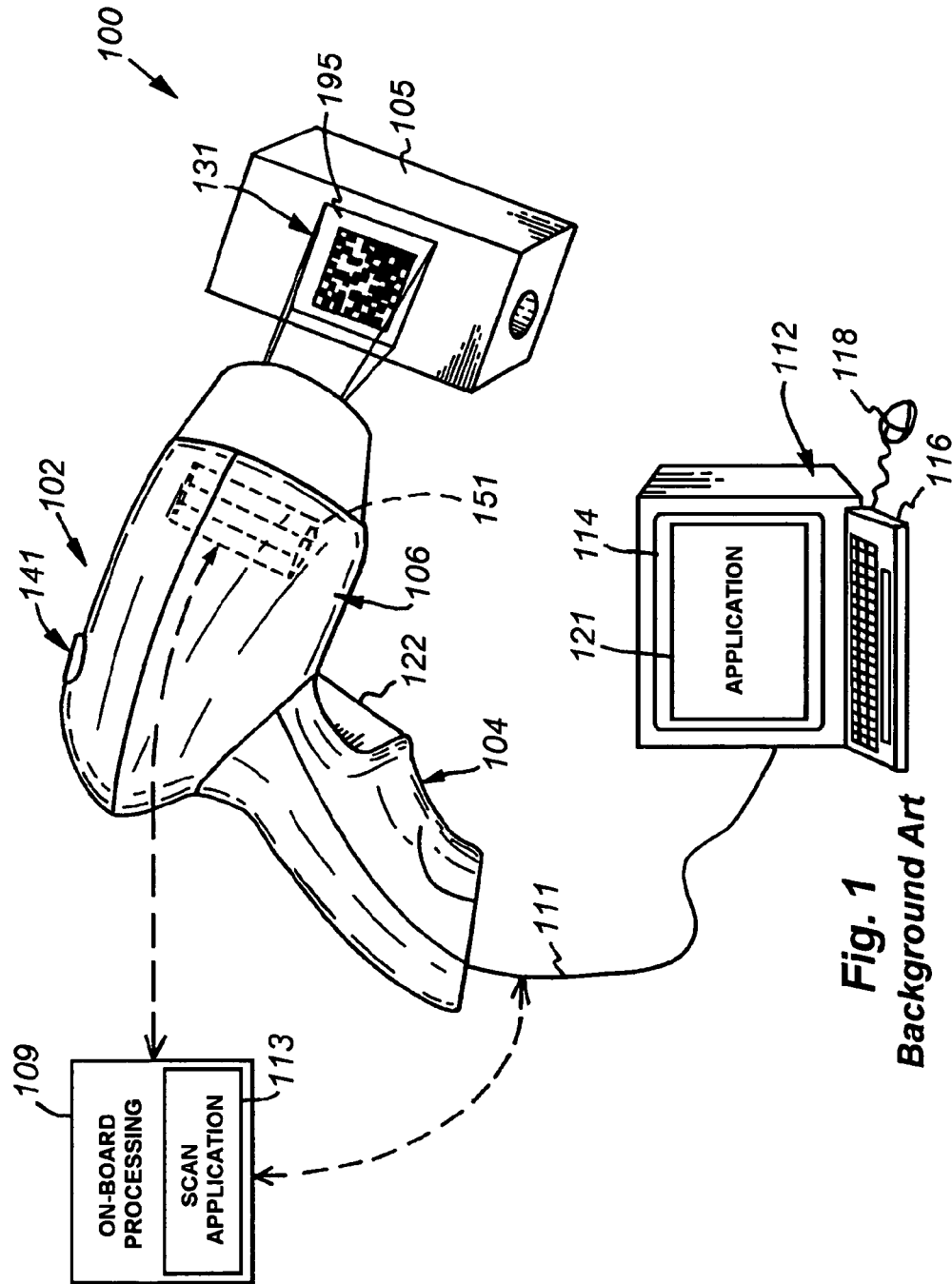


Fig. 1
Background Art

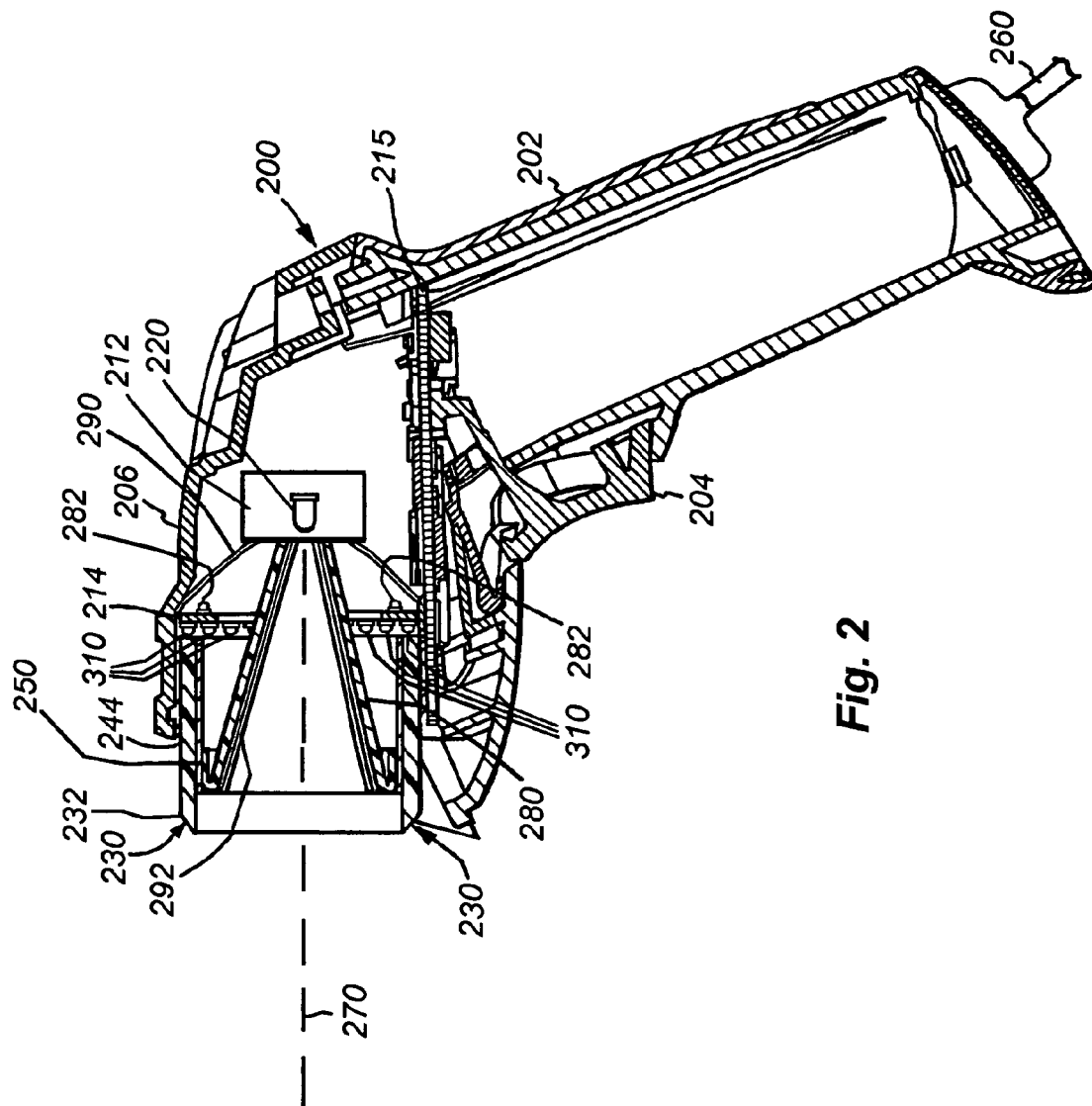


Fig. 2

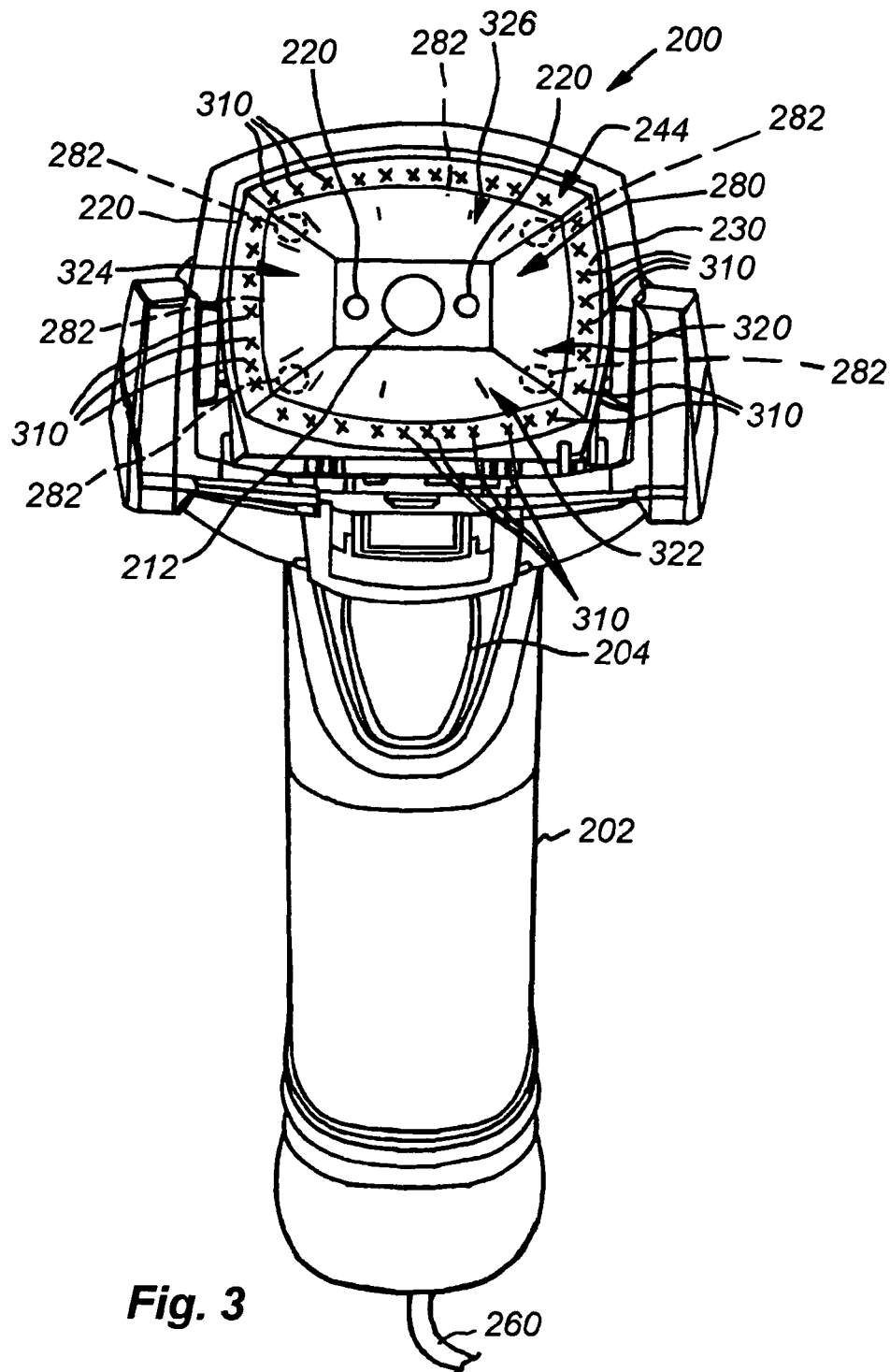


Fig. 3

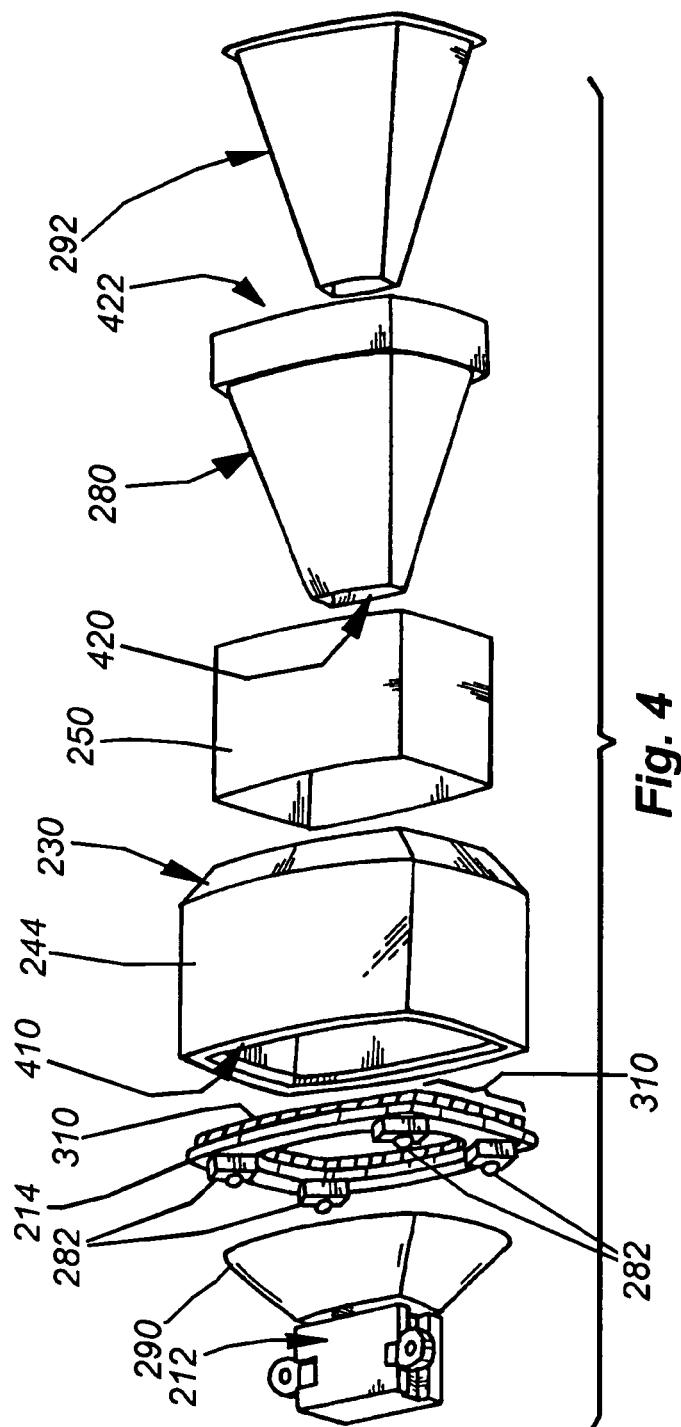


Fig. 4

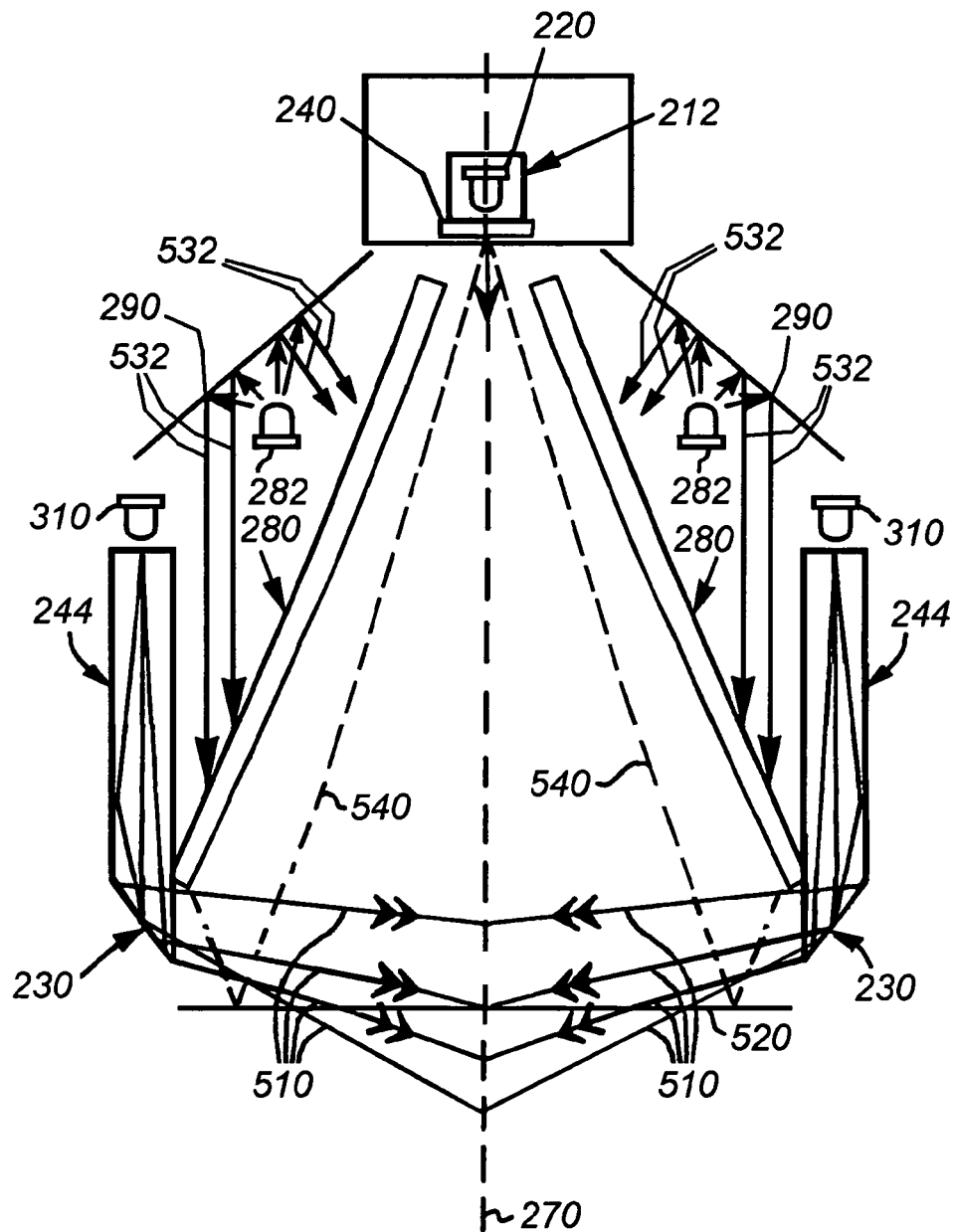


Fig. 5

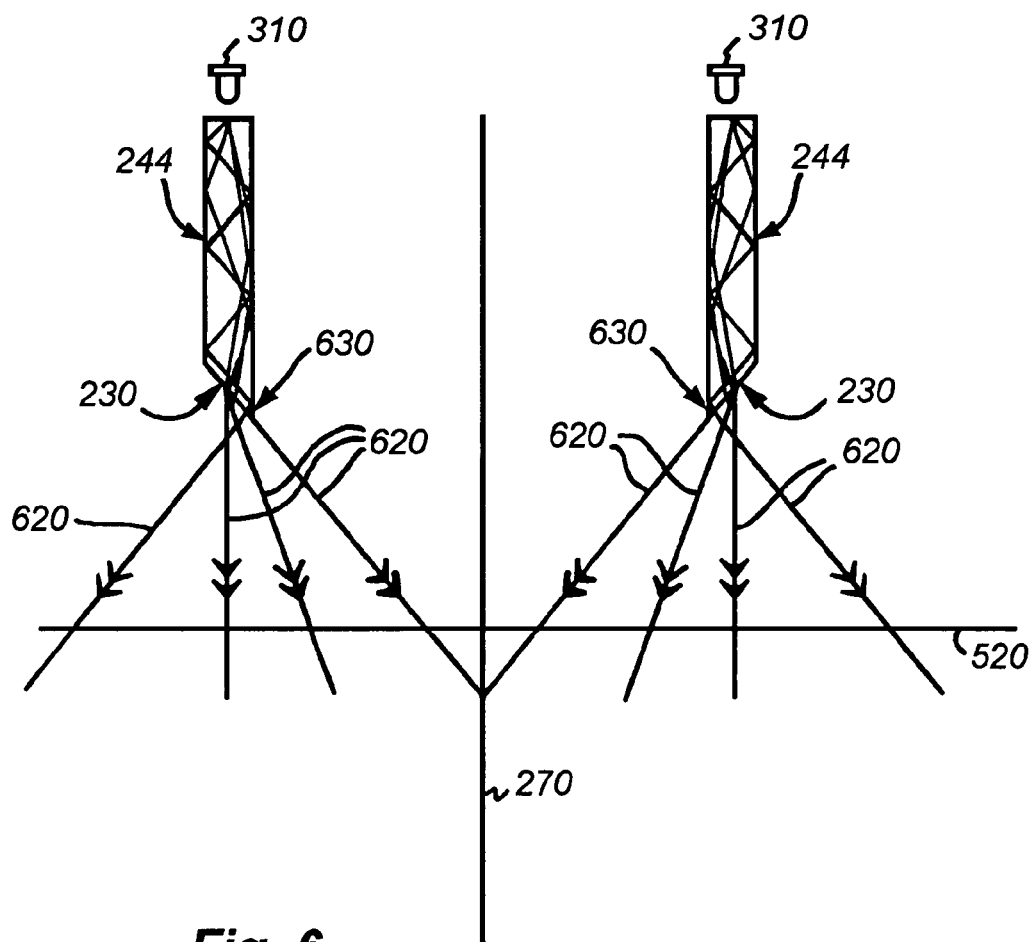


Fig. 6

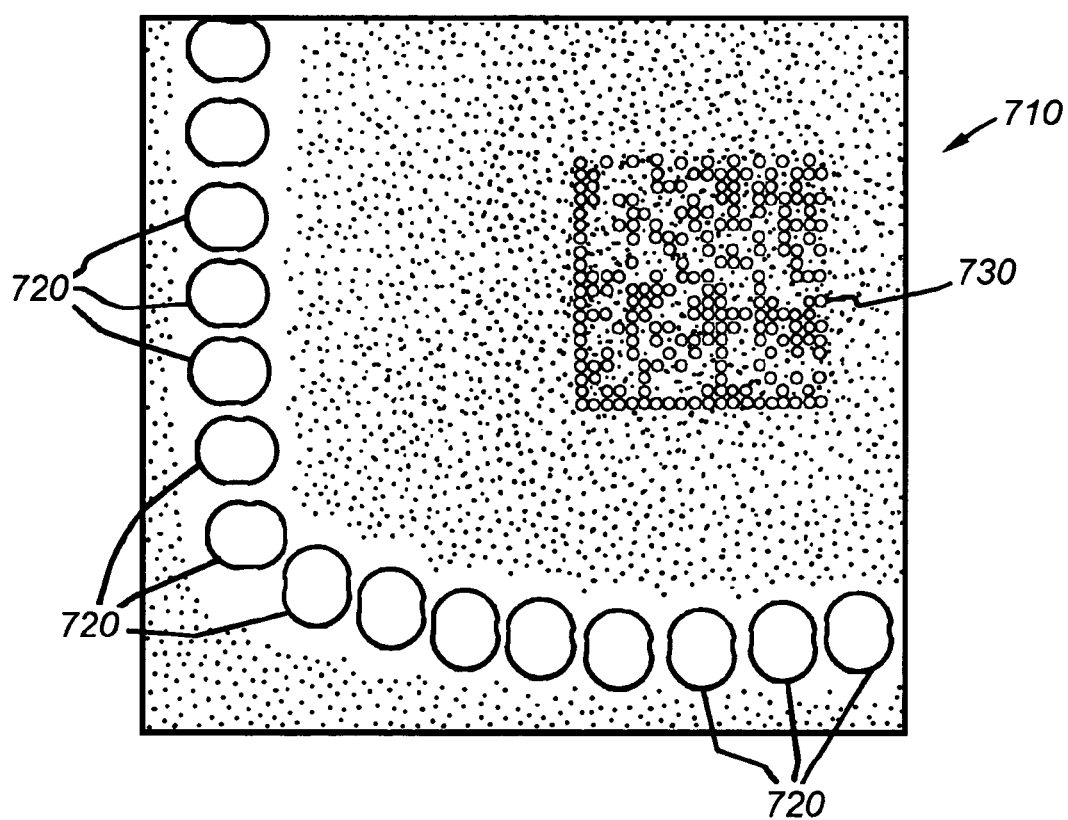


Fig. 7

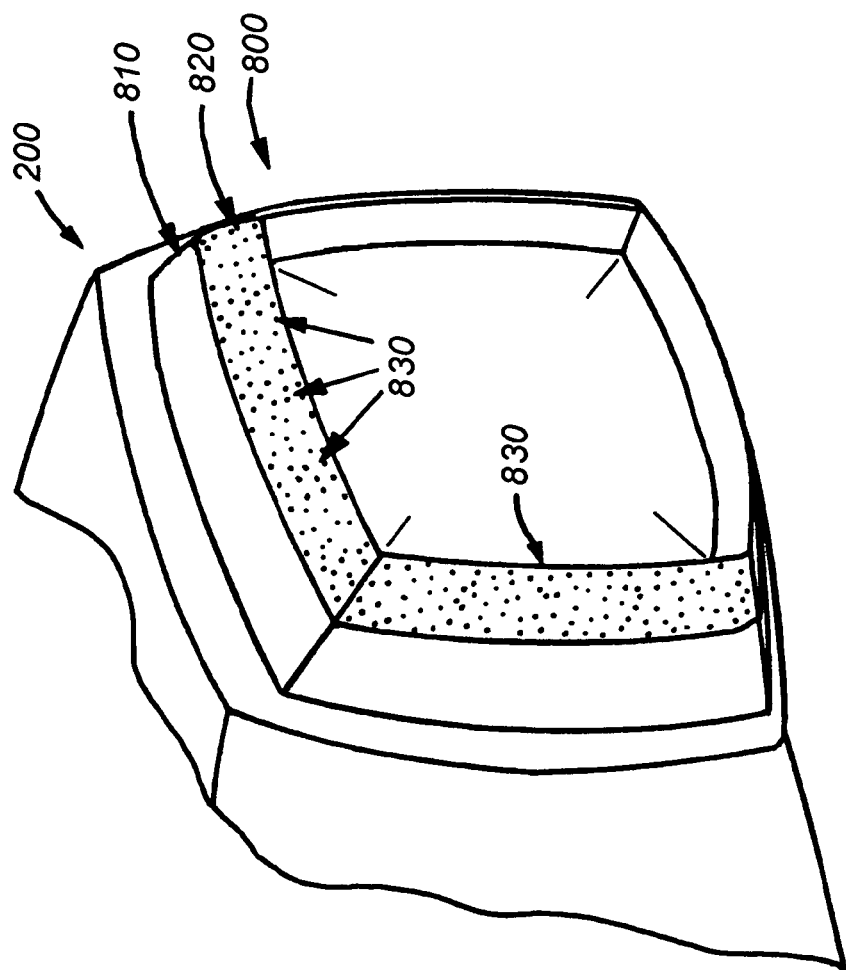


Fig. 8

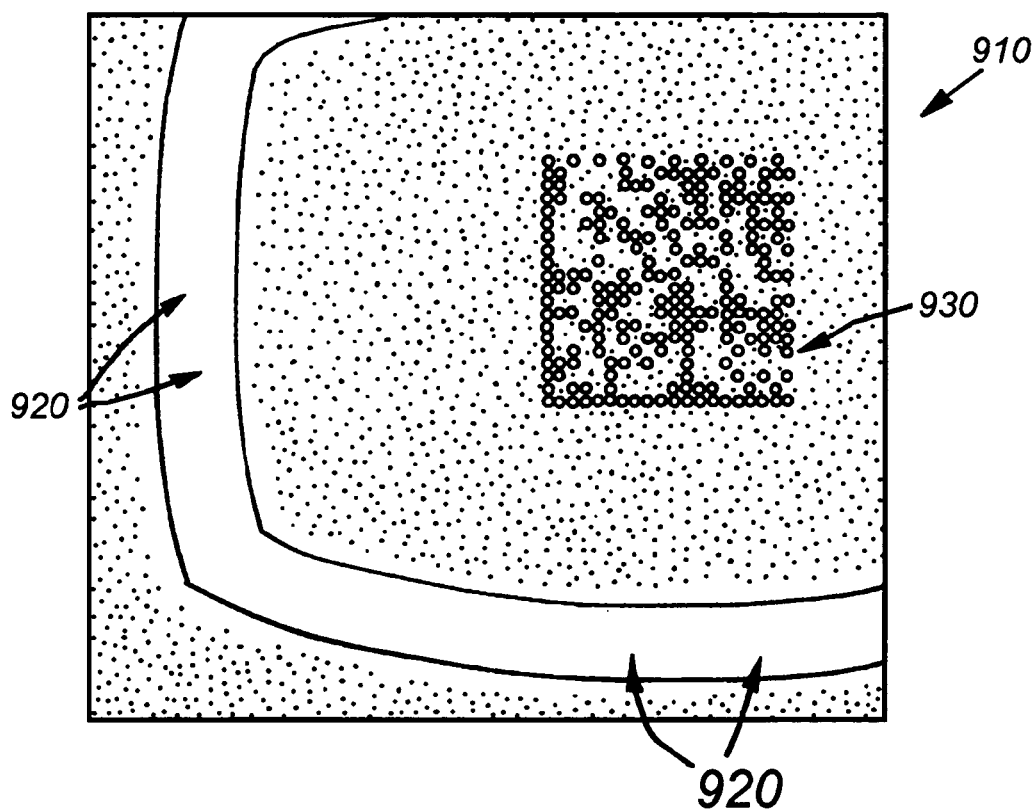


Fig. 9

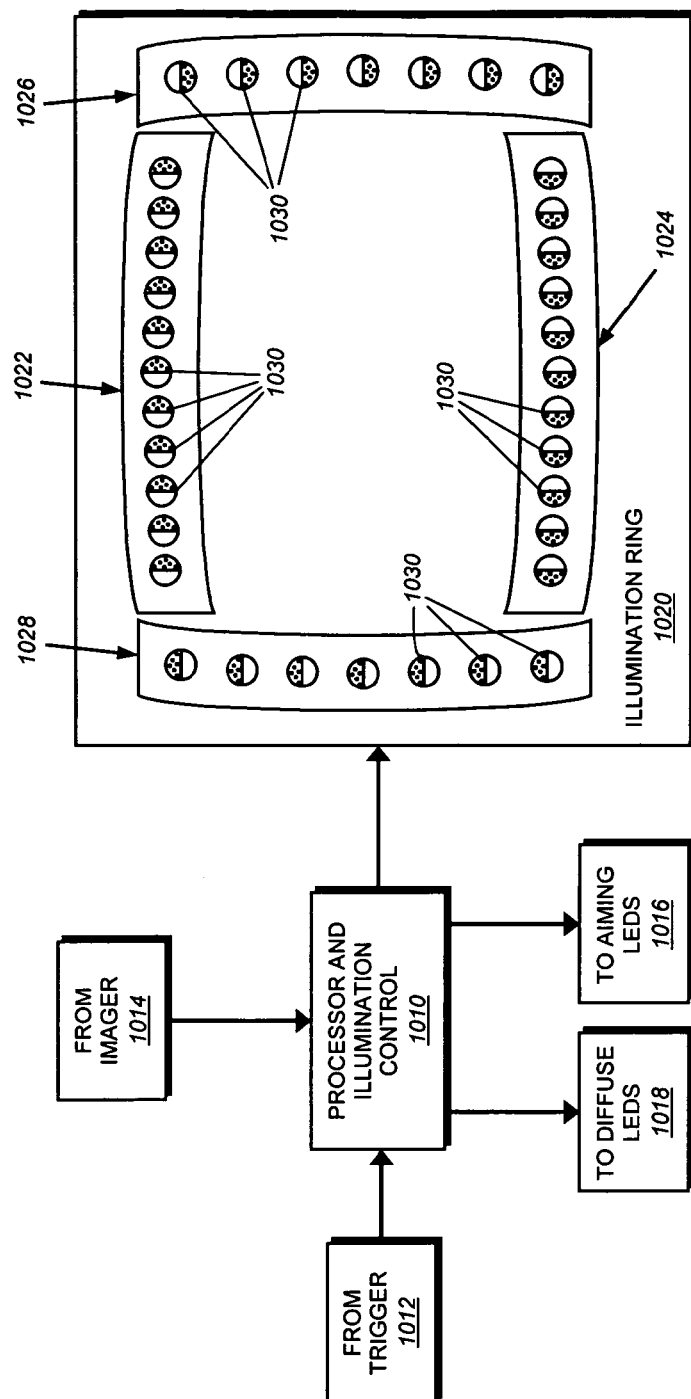


FIG. 10

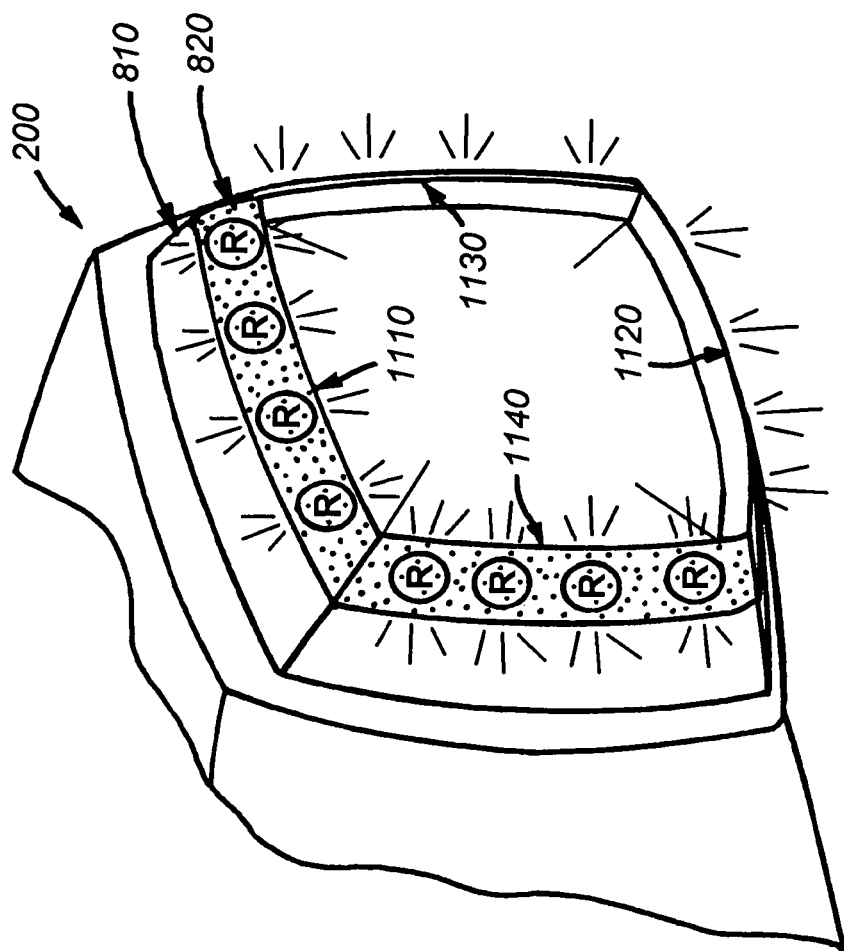


Fig. 11

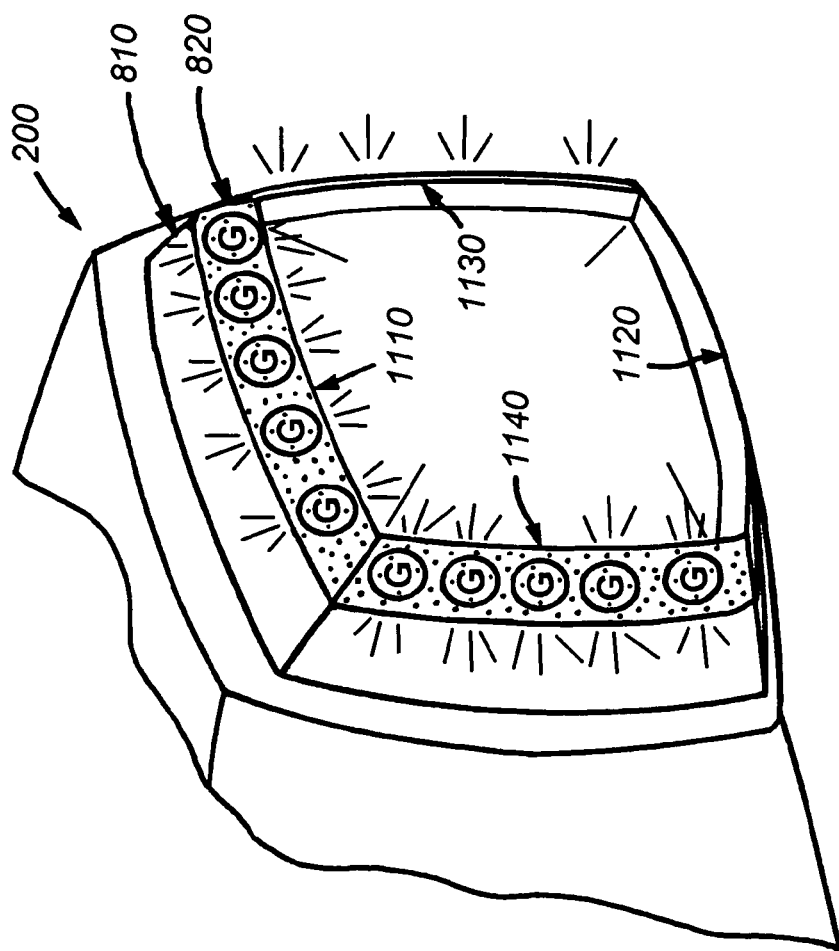


Fig. 12

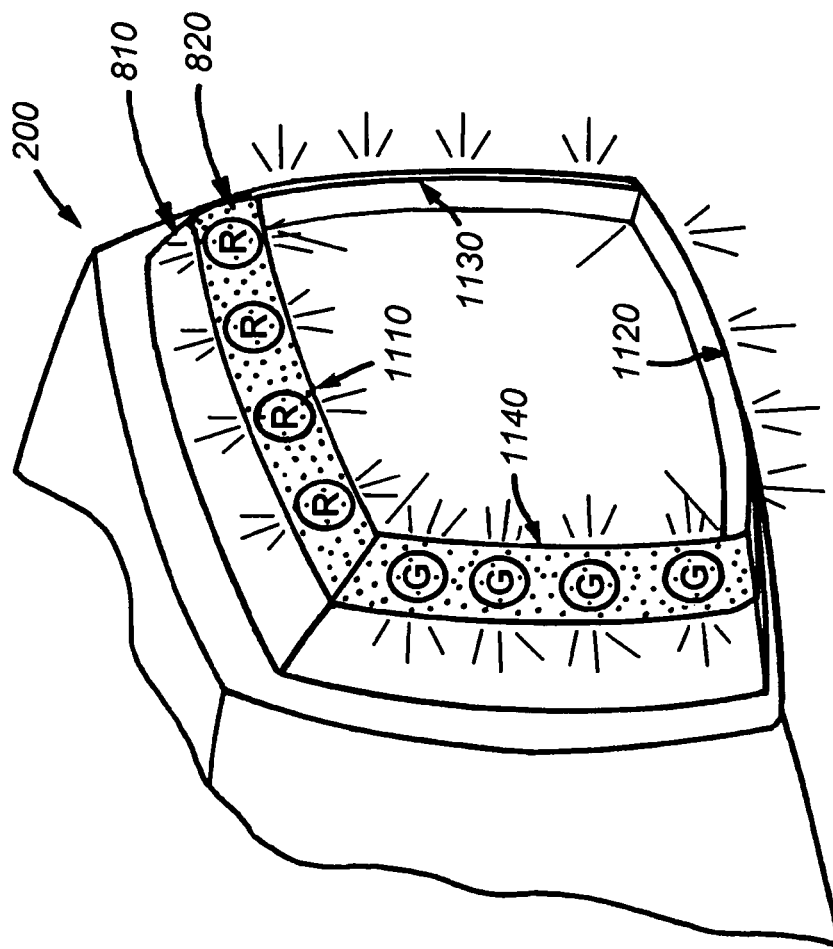


Fig. 13

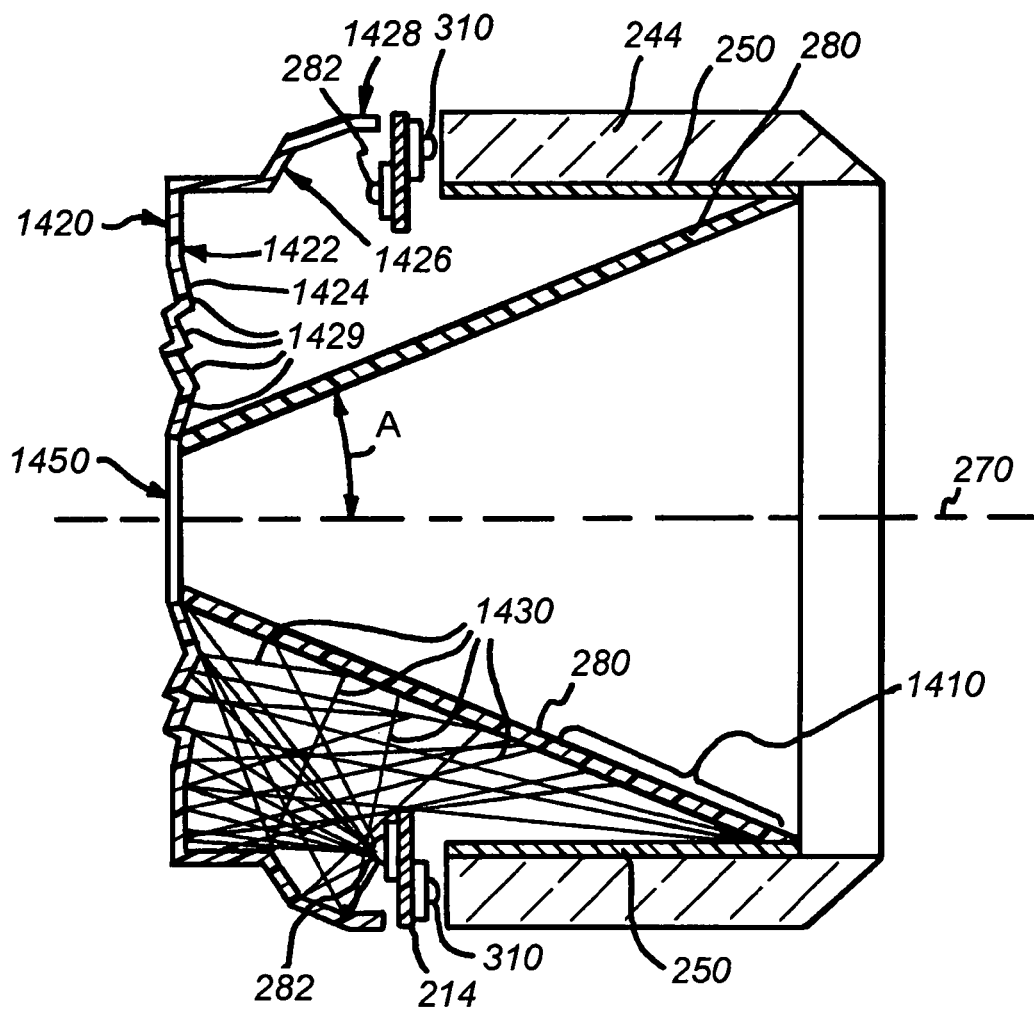


Fig. 14

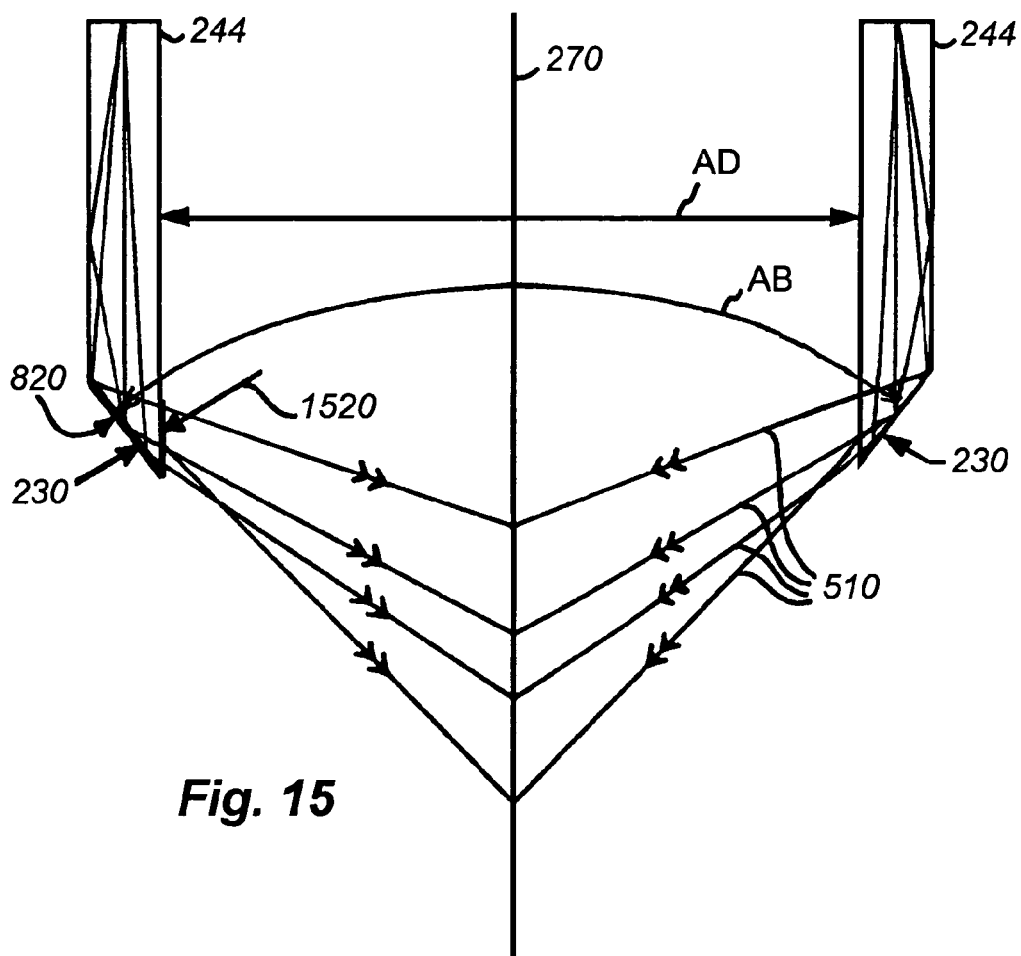


Fig. 15

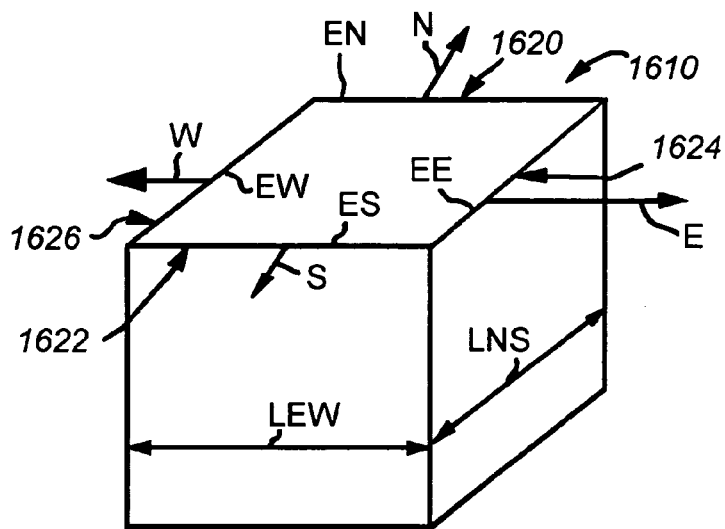


Fig. 16

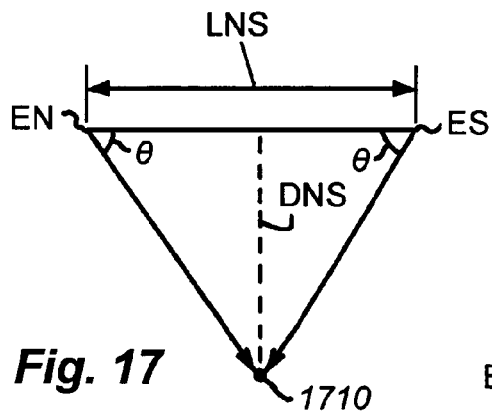


Fig. 17

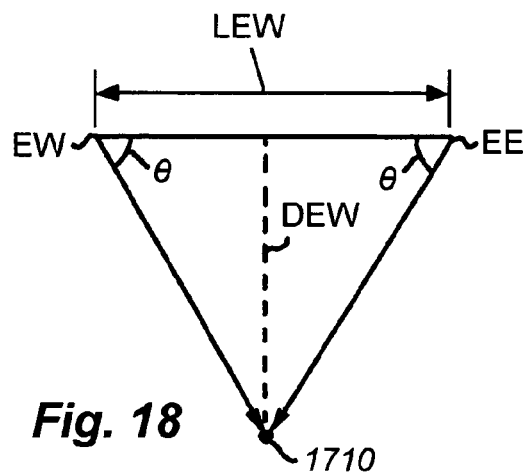


Fig. 18

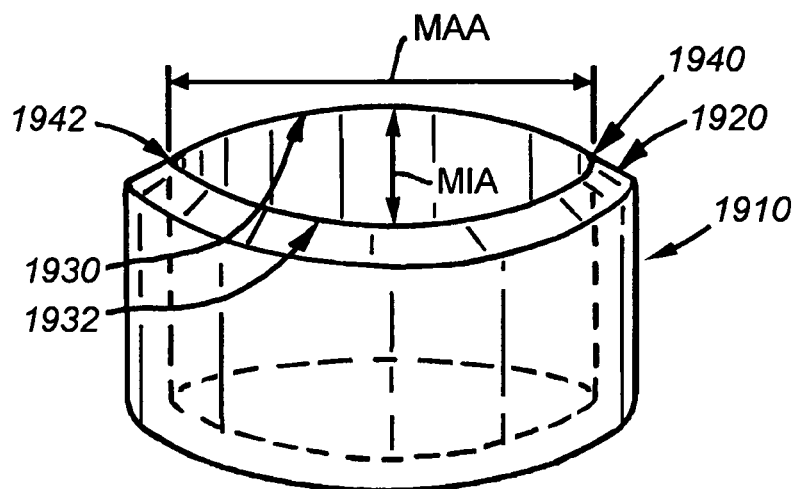


Fig. 19

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INTEGRATED ILLUMINATION ASSEMBLY FOR SYMBOLOGY READER

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/257,411, filed on Oct. 24, 2005, now U.S. Pat. No. 7,874,487 and entitled "Integrated Illumination Assembly for Symbology Reader," which is hereby incorporated by reference.

FIELD OF THE INVENTION

This invention relates to machine vision systems and symbology readers that employ machine vision and more particularly to illuminators for the same.

BACKGROUND OF THE INVENTION

Machine vision systems use image acquisition devices that include camera sensors to deliver information on a viewed subject. The system then interprets this information according to a variety of algorithms to perform a programmed decision-making and/or identification function. For an image to be most-effectively acquired by a sensor in the visible, and near-visible light range, the subject should be properly illuminated.

In the example of symbology reading (also commonly termed "barcode" scanning) using an image sensor, proper illumination is highly desirable. Symbology reading entails the aiming of an image acquisition sensor (CMOS camera, CCD, etc.) at a location on an object that contains a symbol (a "barcode"), and acquiring an image of that symbol. The symbol contains a set of predetermined patterns that represent an ordered group of characters or shapes from which an attached data processor (for example, a microcomputer) can derive useful information about the object (e.g., its serial number, type, model, price, etc.). Symbols/barcodes are available in a variety of shapes and sizes. Two of the most commonly employed symbol types used in marking and identifying objects are the so-called one-dimensional barcode, consisting of a line of vertical stripes of varying width and spacing, and the so-called two-dimensional barcode consisting of a two-dimensional array of dots or rectangles.

By way of background FIG. 1 shows an exemplary scanning system **100** adapted for handheld operation. An exemplary handheld scanning appliance or handpiece **102** is provided. It includes a grip section **104** and a body section **106**. An image formation system **151**, shown in phantom, can be controlled and can direct image data to an on-board embedded processor **109**. This processor can include a scanning software application **113** by which lighting is controlled, images are acquired and image data is interpreted into usable information (for example, alphanumeric strings derived from the symbols (such as the depicted two-dimensional barcode image **195**). The decoded information can be directed via a cable **111** to a PC or other data storage device **112** having (for example) a display **114**, keyboard **116** and mouse **118**, where it can be stored and further manipulated using an appropriate application **121**. Alternatively, the cable **111** can be directly connected to an interface in the scanning appliance and an appropriate interface in the computer **112**. In this case the computer-based application **121** performs various image interpretation/decoding and lighting control functions as needed. The precise arrangement of the handheld scanning appliance with respect to an embedded processor, computer

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or other processor is highly variable. For example, a wireless interconnect can be provided in which no cable **111** is present. Likewise, the depicted microcomputer can be substituted with another processing device, including an onboard processor or a miniaturized processing unit such as a personal digital assistant or other small-scale computing device.

The scanning application **113** can be adapted to respond to inputs from the scanning appliance **102**. For example, when the operator toggles a trigger **122** on the hand held scanning appliance **102**, an internal camera image sensor (that is part of the image formation system **151**) acquires an image of a region of interest **131** on an object **105**. The exemplary region of interest includes a two-dimensional symbol **195** that can be used to identify the object **105**. Identification and other processing functions are carried out by the scanning application **113**, based upon image data transmitted from the hand held scanning appliance **102** to the processor **109**. A visual indicator **141** can be illuminated by signals from the processor **109** to indicate a successful read and decode of the symbol **195**.

In reading symbology or other subjects of interest, the type of illumination employed is of concern. Where symbology and/or other viewed subjects are printed on a flat surface with contrasting ink or paint, a diffuse, high-angle "bright field" illumination may best highlight these features for the sensor. By high-angle it is meant, generally, light that strikes the subject nearly perpendicularly (normal) or at an angle that is typically no more than about 45 degrees from perpendicular (normal) to the surface of the item being scanned. Such illumination is subject to substantial reflection back toward the sensor. By way of example, barcodes and other subjects requiring mainly bright field illumination may be present on a printed label adhered to an item or container, or on a printed field in a relatively smooth area of item or container.

Conversely, where a symbology or other subject is formed on a more-irregular surface, or is created by etching or peening a pattern directly on the surface, the use of highly reflective bright field illumination may be inappropriate. A peened/etched surface has two-dimensional properties that tend to scatter bright field illumination, thereby obscuring the acquired image. Where a viewed subject has such decidedly two-dimensional surface texture, it may be best illuminated with dark field illumination. This is an illumination with a characteristic low angle (approximately 45 degrees or less, for example) with respect to the surface of the subject (i.e. an angle of more than approximately 45 degrees with respect to normal). Using such low-angle, dark field illumination, two-dimensional surface texture is contrasted more effectively (with indents appearing as bright spots and the surroundings as shadow) for better image acquisition.

In other instances of applied symbology a diffuse direct illumination may be preferred. Such illumination is typically produced using a direct-projected illumination source (e.g., light emitting diodes (LEDs)) that passes through a diffuser to generate the desired illumination effect.

To take full advantage of the versatility of a camera image sensor, it is desirable to provide bright field, dark field and diffuse illumination. However, dark field illumination must be presented close to a subject to attain the low incidence angle thereto. Conversely, bright field illumination is better produced at a relative distance to ensure full area illumination.

Commonly assigned U.S. patent application Ser. No. 11/014,478, entitled HAND HELD SYMBOLOGY READER ILLUMINATION DIFFUSER and U.S. patent application Ser. No. 11/019,763, entitled LOW PROFILE ILLUMINATION FOR DIRECT PART MARK READERS,

both by Laurens W. Nunnink, the teachings of which are expressly incorporated herein by reference, provide techniques for improving the transmission of bright field (high angle) and dark field (low angle) illumination. These techniques include the provision of particular geometric arrangements of direct, bright field LEDs and conical and/or flat diffusers that are placed between bright field illuminators and the subject to better spread the bright field light. The above incorporated HAND HELD SYMBOLOLOGY READER ILLUMINATION DIFFUSER further teaches the use of particular colors for improving the illumination applicable to certain types of surfaces. Often, the choice of bright field, dark field, direct or diffuse light is not intuitive to user for many types of surfaces and/or the particular angles at which the reader is directed toward them. In other words, a surface may appear to be best read using dark field illumination, but in practice, bright field is preferred for picking out needed details, especially at a certain viewing angle. Likewise, with handheld readers, the viewing angle is never quite the same from surface to surface (part-to-part) and some viewing angles be better served by bright field while other may be better served by dark field. The above-referenced patent applications contemplate the application of a plurality of illumination types to achieve the best image for a particular surface and viewing angle.

It has been recognized that handheld readers pose a number of unique concerns. At least some of these concerns are shared in relation to fixed readers. For example, the material from which most light pipes are constructed is acrylic (commonly termed "plexiglass"). Acrylic exhibits a high refractive index (approximately 1.58), which is well suited for internal transmission of light down a light pipe. However, acrylic tends to shatter easily in response to impact. This may limit the life and endurance of a handheld reader (particularly a cordless/wireless model) that is expected to occasionally drop and strike a hard floor, perhaps against the light pipe. While the light pipe could be armored with cushioning and external housings, this undesirably increases production costs, weight, obtrusiveness and may optically obscure the pipe.

Moreover, the light pipes described in the above referenced patents may include a chamfered end to project dark field illumination via internal reflection. Refraction through the polished chamfered end also generates direct bright field illumination. The optical clarity of the light pipe and end tends to create a spotlight effect, in which each individual illumination source (red LEDs, for example) is clearly visible on certain surfaces (see FIG. 7 below). This controverts the typical goal of providing an even spread of illumination.

Also, where a conical diffuser is employed to provide an overall source of direct diffuse illumination, prior art devices are limited in their ability to spread light from a few individual illumination sources (LEDs, for example) throughout the diffuser surface, and then onto the subject as diffuse light. Thus, the diffuse light tends to exhibit a characteristic, localized light spot and dark spot effect. Adding further illumination sources to the diffuse section may be limited both by space and the relative cost of illumination sources, particularly where relatively costly blue-colored LEDs are employed.

Further, prior art readers often include visual indicators located at their back, top or another surface that denote the current status of the reader (for example, power on/off, good read, error, bad read, ready, not-ready, etc.). Various information can be presented to the user via different color lights (red/green, for example) and/or via blinking patterns. However, in a production environment, small, rear-mounted or top-mounted indicators may be overlooked or present a dis-

traction while the user tries to focus on the surface being read. A technique for more-conveniently integrating indicators with the user's main point of interest is highly desirable.

SUMMARY OF THE INVENTION

This invention overcomes the disadvantages of the prior art by providing a plurality of novel features that can be applied variously to a reader to improve the illumination performance in both dark field/direct bright field and direct diffuse types of illumination. Further features allow for increased light pipe durability without increasing weight or size and better readability of status indicators by placing such indicators in proximity to the subject and significantly enlarging to overall size of the indicator.

In one embodiment, the light pipe is constructed from durable polycarbonate for increased shock resistance. The chamfered end of the light pipe is textured or frosted to further diffuse refracted light passing through the end so as to present a more even effect. The conical/tapered diffuser within the light pipe is illuminated by a reflector with a white textured surface that reflects a plurality of rearward-directed (opposite the illumination and viewing direction) illumination sources back into the diffuser. The reflector can define a predetermined cross section that directs further light into the forward-most, remote regions of the diffuser to generate a better overall spread of light and alleviate light and dark spotting effects. The textured surface on the chamfered light pipe end can be employed to better project indicator light. The textured surface can alternatively (or in addition) be applied to the exposed portion of the inner wall adjacent to the distal (forward) end of the pipe.

The illumination sources are arranged in a ring at the inner end of the light pipe, and can be multi-colored sources that respond to the controller to project and appropriate color and/or blink in an appropriate pattern to indicate various conditions, such as read success or failure. Typically the controller is adapted to provide these specialized indications between actual image acquisition, so that the image acquisition is properly illuminated. The controller can operate individual portions of the ring so that only corresponding portions of the light pipe perimeter are illuminated in a particular color (quadrants, for example) at a given time. Different quadrants may be simultaneously illuminated in different colors in one example.

In an illustrative embodiment, the light pipe defines a polygonal (for example rectangular) cross section (with the polygon being generally defined as at least four linear or non-linear sides, joined at corners (that may be rounded) to form a (typically) non-equilateral shape. The chamfered edge on each side is at a fixed angle and thus the differing length of the North-South versus East-West sides (in the case of a rectangle), generates two different distances for convergence of dark field rays, which increases depth of field. Stated differently, the polygon (rectangle) includes at least two pairs of opposing sides and the first pair of opposing sides has a length different than the second pair of opposing sides to generate two differing-distance convergence points for dark field rays.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention description below refers to the accompanying drawings, of which:

FIG. 1, already described, is a perspective view of a handheld scanning system with integrated illumination according to the prior art;

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FIG. 2 is a side cross section of a handheld scanning system that can be employed in connection with the teachings of this invention;

FIG. 3 is a front view of the scanning system of FIG. 2;

FIG. 4 is an exploded view of the illumination assembly and image sensor for the scanning system of FIG. 2;

FIG. 5 is a somewhat schematic side cross section of the sensor and illuminator assembly for use with the scanning system of FIG. 2 detailing the path taken by various illumination types;

FIG. 6 is a somewhat schematic side cross section of the light pipe of the illuminator assembly of FIG. 5 more particularly showing the projection of direct bright field illumination;

FIG. 7 is a diagram showing an illumination effect in which individual illumination sources are projected onto a surface through a polished chamfered light pipe end;

FIG. 8 is a fragmentary perspective view of the viewing end of the reader featuring the illumination assembly and having a textured surface on the chamfered light pipe end;

FIG. 9 is a diagram showing an illumination effect achieved on a surface employing a textured chamfered light pipe end in accordance with an embodiment of this invention;

FIG. 10 is a block diagram of the image processor and illumination control circuitry interacting with the sensor, trigger and illumination ring, featuring individual quadrant control and multi-color illumination sources;

FIG. 11 is a fragmentary perspective view of the viewing end of the reader showing the textured chamfered light pipe end illuminated in red as an indicator;

FIG. 12 is a fragmentary perspective view of the viewing end of the reader showing the textured chamfered light pipe end illuminated in green as an indicator;

FIG. 13 is a fragmentary perspective view of the viewing end of the reader showing the textured chamfered light pipe end illuminated in red in predetermined quadrants and green in other predetermined quadrants as an indicator;

FIG. 14 is a schematic side cross section of the light pipe, diffuser, illumination sources and reflector showing a predetermined reflector geometry so as to increase projection of light along remote regions of the diffuser;

FIG. 15 is a somewhat schematic side cross section of the light pipe of the illuminator assembly detailing the draft angle provided to allow molding of the light pipe and showing an alternative placement of the diffusive surface at the distal end of the light pipe;

FIG. 16 is a schematic diagram of a generalized shape for a rectangular cross section light pipe featuring representations of a North, South, East and West edge;

FIG. 17 is a schematic representation of the convergence of dark field rays from the North and South edges of the light pipe of FIG. 16 showing a first distance thereto;

FIG. 18 is a schematic representation of the convergence of dark field rays from the East and West edges of the light pipe of FIG. 16 showing a first distance thereto; and

FIG. 19 is an exposed perspective view of a light pipe according to an alternate embodiment of this invention defining an elliptical cross section.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

FIG. 2 shows a cross sectional side view of an illustrative embodiment of the reader 200 according to the present invention. The imager 212 and an illumination board 214 are positioned on a shock-resistant mounting (not shown) within the housing 206. In this exemplary embodiment, the processor

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module and related functional electronic components are mounted on a processor board 215. The grip portion 202 and the trigger 204 are functionally cooperative with the housing 206 and components of the processor board 215. The grip portion 206 includes a conveniently placed trigger 204 that can be actuated by a finger of the user to initiate the image acquisition and decoding function. More particularly, pressing the trigger causes all types and colors of illumination (as described further below) to be simultaneously projected onto the subject of interest, and also causes corresponding acquisition of an image by the imager.

With brief reference to the illuminator, the illumination board 214 supports a plurality of LEDs 310 that are red in this embodiment (a variety of colors can be used). The LEDs 310 are directed forwardly, toward the opening of the reader. These LEDs are positioned behind a passive light pipe 244 that internally transmits light from the ring of LEDs 310 to a front end 230. In this embodiment, the front end 230 includes a chamfered surface 232. Various examples of a light pipe for use with a reader or similar application are shown and described in U.S. patent application Ser. No. 10/693,626, entitled LIGHT PIPE ILLUMINATION SYSTEM AND METHOD, by William H. Equitz, et al., the teachings of which are expressly incorporated herein by reference.

Briefly explained, light passes through the extended body of the pipe 244 from the inner end, adjacent to the LEDs 310. The body is formed from a transmissive/transparent substance. As discussed above, one concern for the light pipe is durability and impact resistance. In an embodiment of this invention, the light pipe is constructed from transparent polycarbonate (available under the trade name Makrolon from BASF of Germany, or alternatively Lexan® available from the General Electric Company). This substance can be injection-molded using a liquid resin that is formed into a desired shape as discussed further below. The transmitted light is reflected internally by the angled/chamfered surface 232 of the light pipe 244 to exit at a low angle toward the center optical axis 270. While acrylic displays a superior refractive index (approximately 1.58), it has been recognized that the refractive index of polycarbonate (approximately 1.49) is sufficient to achieve the degree of light transmission and internal reflection employed for dark field illumination in accordance with embodiments of this invention. The inner and/or outer wall surfaces of the light pipe 244 can be coated with opaque paint or another compound to prevent leakage of light into or out of the pipe. In this example, a shield 250 is also provided along the inner surface of the light pipe. One function of the shield 250 is to prevent transmission of diffuse light (described below) in to the light pipe. Another function is to redirect light transmitted from the reflector (see below) back into the diffuser.

In this example, the ring of LEDs 310 acts to produce a red direct bright field effect along with the dark field effect through refraction of some light from the LEDs through the chamfered surface 232. In general, at short reading distances from a surface (<25 mm between the light pipe distal (forward) end 230 and surface), the bright field illumination from the light pipe 230 tends not to interfere with the dark field illumination. The bright field illumination is available, however, for larger reading distances (>25 mm between the end 230 and the surface). This is useful for easy-to-read codes, such as black-and-white printed labels. In alternate embodiments, a separate bright field illuminator can be provided, and as described below. In fact, many available imagers include integral red bright field illuminators. In an alternate embodiment, a separate bright field illuminator can be provided in a discrete color, such as green.

Note that a pair of aiming LEDs **220** (typically emitting green light) are provided. However, these are optional. Such aiming LEDs may be integral with the commercially available image employed herein.

A tether cord **260** provides electrical power to the reader **200**, as well as a communication transmission path for the decoded character string of the encoded information, though it is contemplated that the reader **200** can be configured with battery power and wireless communication for complete portable flexibility.

With reference also to FIG. 3, a front view of the reader **200** is shown. The distribution and placement of the individual LEDs (or other appropriate light elements) **310** that transmit light to the light pipe **244** is represented by a series of adjacent Xs positioned around the perimeter of the light pipe **244** in line with the distal end **230**. The illustrative LED placement creates a generally uniform lighting effect. The placement of these light elements and others used herein is highly variable. In addition, the addressing of light elements can be controlled so that only certain elements are activated at certain times to create the desired overall dark field illumination intensity and/or bias (e.g., lighter on one side than another) to the dark field illumination effect on the subject. This variable-addressing feature is described further below and is discussed in further detail in the above-incorporated U.S. patent Applications and in other commonly assigned U.S. patent Applications referenced therein.

Reference is now also made to the exploded view of FIG. 4, which further details the components of the overall illuminator assembly with respect to the imager **212**. As shown, the various illuminator assembly components, described above have been separated to reveal individual structural details. The imager **212** resides at the left side of the view. The illumination board assembly **214** is located ahead of it. Placed in front of the illumination board **214** and LEDs **310** is the proximal (or base) end **410** of the light pipe **244**, which receives transmitted light from the LEDs **310**, and internally transmits it to the chamfered distal end **230**. A tapered (also loosely termed “conical”) diffuser **280** (refer also to FIG. 2) is nested within the light pipe **244**, with a narrowed proximal opening **420** provided adjacent to the imager **212** and a widened distal opening **422** located at the opposing end. In an illustrative embodiment, this diffuser **280** can be constructed from a thin (1-3 millimeter) polymer material with a frosted/textured interior. As noted above, a thin shield **250** is provided against the interior of the light pipe to block the diffuser’s transmitted light from entering the light pipe **244**. In this manner, the light emitted from the diffuser does not mix with the light pipe’s transmission.

Space may be limited in the region between the shield **250** and the inner surface of the diffuser **280**. Moreover, it is contemplated in various embodiments to provide a blue color for the diffuse illumination, employing high-output, blue-colored LEDs, which are more costly than the red or green versions. Thus, use of a smaller number of such LEDs is highly desirable. The fewer individual illumination sources employed, the greater the need to spread the light around the diffuser so as to avoid a light and dark spotting effect on the surface of interest. To accomplish the desired spread of diffuse illumination with a minimal number of individual illumination sources, the light projected by the diffuser is provided by a set of (four) rearward-projecting LEDs **282** mounted on the illumination board **214** on a side opposite the ring of light pipe LEDs **310**. These LEDs **282** project rearward into a conical, spherical, parabolic (or other shape) reflector **290** that spreads the reflected light throughout the inner surface of the diffuser **280** so that it exits as a substan-

tially uniform spread of direct, diffuse light onto the surface of interest. As will be described further below, the reflector’s shape can be optimized to improve the spread of light along the conical diffuser. In this embodiment, the reflector **290** is constructed from polymer with a white textured surface to further diffuse the light reflected therefrom. This indirect projection of light with a diffusing reflective surface significantly aids in reducing the number of diffuse illumination LEDs **282** employed to project the diffuse illumination, thereby reducing production costs and power consumption. As noted above, in this embodiment, the diffuse illumination LEDs **282** are high-output blue LEDs. However, the particular colors used for each type of illumination are highly variable. However, it is highly desirable that the diffuse illumination be spaced apart on the spectrum sufficiently from the dark field illumination to allow adequate resolution of the two wavelengths of light.

A translucent “conical” filter **292** is provided. The filter **292** is adapted to filter out light with larger wavelengths, thereby allowing smaller wavelength blue light to pass out of the diffuser and onto the surface, but preventing the retransmission of any reflected red light from the surface, which would otherwise tend to become retransmitted as diffuse red light along with the red dark field illumination. The wavelength spread between red light and blue light is sufficient to accomplish this filtering without compromising the performance of either type (dark field/direct bright field versus direct diffuse) of illumination. The filter **292** conforms to the shape of the diffuser’s outer (exposed) surface, and can be snapped or adhered onto the diffuser surface using a variety of fastening techniques that should be clear to those of ordinary skill. Note that instead of a separate filter (**292**), a similar effect can be obtained through the use of a colored diffuser (see FIG. 6 below). The color should be selected so that the diffuser transmits the diffuse light (blue in this embodiment), but does not reflect the dark field light (red in this embodiment) transmitted from the light pipe.

Thus, to summarize, at least two discrete sets of illumination transmitters (LEDs, for example) are provided according to the illustrative embodiment, the direct diffuse transmitters **282** and the dark field transmitters **310**. In accordance with the illustrative embodiment, each discrete set of transmitters **282** and **310** generates a corresponding discrete illumination color. For example, direct diffuse illumination can be generated by blue LEDs and dark field (and direct bright field) can be generated by red LEDs. The use of two discrete colors allows each type of illumination to be restricted to its particular application, without mixing, using filtering within the illumination assembly. In this embodiment, each type of illumination creates an image that is received by the imager **212**. The imager in this embodiment includes a conventional monochrome sensor that produces a grayscale image from the colored light. Note in alternate embodiments a color sensor can be employed. One such implementation is shown and described in commonly assigned U.S. patent Application entitled SYSTEM AND METHOD FOR EMPLOYING COLOR ILLUMINATION AND COLOR FILTRATION IN A SYMBOLOGY READER by Laurens W. Nunnink, and filed on even date herewith, the teachings of which are expressly incorporated herein by reference.

Reference is now made to FIGS. 5 and 6, which describe generally the illumination patterns achieved by the light pipe **244** and diffuser **280** of the illumination assembly. Referring first to FIG. 5, a cross section of an implementation of the diffuser **280** is shown, with light pipe **244** as described generally above, relative to the imager assembly **212** (and associated lens structure **240**). Dark field illumination (rays **510**)

is directed into the light pipe **244** that is internally reflected at the chamfered distal (forward) end **230** to be, thus, directed at the object surface **520** at a low angle. Further information regarding the basic design and implementation of passive light pipes with selectively actuated illumination to provide dark field illumination can be found in the above incorporated U.S. patent application Ser. No. 10/693,626, entitled LIGHT PIPE ILLUMINATION SYSTEM AND METHOD, by William H. Equitz, et al. Direct illumination (rays **532**) from blue LEDs **282** is converted into totally diffuse direct illumination by reflection off the reflector **290**, and passage into and through the diffuser **280** of this embodiment. The diffuser **280** thereby projects diffuse illumination on the object surface **520** within the field of view, depicted as the region defined by dashed lines **540**. In this embodiment the diffuser **280** is, itself, translucent, without a color tint or color-filtering effect. In alternate embodiments, the diffuser can be tinted to generate a desired color and/or act as a filter (using colored or white illumination sources (**282**)). It should be noted that the diffuser **280** according to this embodiment, and other embodiments described herein, can be constructed and arranged so as to be removably attached to the hand held scanning appliance. In one example, the diffuser can be removed to allow the transmitters **282** to operate as non-diffuse direct bright field illumination. Alternatively, the diffuser can be provided with movable shutters that selectively expose clear (nonfrosted/non-diffusing) windows in the overall diffuser. The removability of the diffuser **280** can be achieved by incorporating snap-fit clearances and/or features in the diffuser and light pipe **242** that permit removable assembly (not shown).

In this embodiment direct non-diffuse bright field illumination (see rays **620** in FIG. 6) is provided by refraction of light through the chamfered end **230** of the light pipe **244**. As shown particularly in FIG. 6, a portion of the light internally reflected along the pipe **244** exits directly from the chamfered end **230** as relatively high-angle (usually greater than 45 degrees relative to the axis surface **520**) bright field light (rays **620**). The remaining light is internally reflected by the chamfered end **230** to exit adjacent to the inner corner **630** of the pipe **244** as discussed generally above. Note that the light pipe can be modified in alternate embodiments to include a flattened ring residing in a plane perpendicular to the axis **270**. This would permit additional bright field light to be directly transmitted onto the surface **520**. Likewise, a nested light pipe with a flat (un-chamfered) ring formed at its distal end can be used in alternate embodiments for direct transmission of bright field light along a waveguide separate from the depicted dark field light pipe **244**. This can be useful where illuminators having a discrete color are used for direct bright field light. Alternatively, where optional direct bright field transmitters are employed they can be located so as to project light through clear/transparent portions (not shown) of the diffuser **280**.

While not shown in this illustration for simplicity, it can be assumed that a filter (**292** above) may be applied over the diffuser to prevent migration of reflected dark field (and bright field) light into the diffuser **280**.

As discussed in the above Background of the Invention, illuminator light pipes according to various prior implementations of mark readers include a polished distal end. Referring briefly to FIG. 7, an image **710** acquired of a reflective surface using a light pipe with a polished end is shown. This image **710** clearly depicts delineated spots **720** produced by the individual illumination sources in the illumination ring. These spots lead to a somewhat broken illumination pattern that may effect acquisition of the mark **730**.

Referring to FIG. 8, the reader **200** is fitted with an illumination assembly **800** that includes a light pipe **810** according to an embodiment of this invention. The light pipe **810** includes a chamfered end **820** about its forward perimeter having a general size and shape as described above. Notably, the depicted outer surface **830** of the chamfered end **820** is finely frosted or textured. This provides a mild diffusive effect to light exiting as direct bright field illumination (see FIG. 6) and also to internally reflected light exiting as dark field illumination. The resulting diffusion generates the image shown in FIG. 9. Note that the ring of light **920** surrounding the mark **930** is more uniform and the mark, itself, appears better contrasted than the results of the polished-end version shown in FIG. 7.

The frosted or textured surface **830** provided along the chamfered end facilitates a novel and desirable display of reader status according to an embodiment of this invention. Before describing the status display in detail, reference is made to FIG. 10, which schematically describes the basic components of the illumination and image processing system of the reader. The circuit board (**215** in FIG. 2) of the reader includes a processor and illumination controller, shown schematically as processor/control block **1010**. The processor/control **1010** can employ conventional image processing and mark-recognition/decoding processes. The processor/control **1010** receives signals from the trigger (block **1012**), which are used to operate the illumination assembly and to obtain image data via the imager (block **1014**). The aiming LEDs (block **1016** and see also **220** in FIG. 2) are operated before and during image acquisition under control of the processor. These serve to keep the user aimed at the mark during the acquisition process, particularly where the scan is performed at a standoff distance from the object surface. To his end, it is noted that acquisition of the image according to this embodiment involves a stepping through of a plurality of illumination types (dark field and diffuse) in timed sequence, with associated image acquisition of the mark during each type of illumination. Typically the best image (or a combination of the images) is chosen to decode the data represented by the mark. Before acquisition, and after acquisition, the reader may indicate a variety of status codes, such as ready-to-read, read successful, read unsuccessful, etc. These indicators are described further below.

During the stepping process, the processor **1010** directs the illumination ring (block **1020**) to illuminate. It then directs the diffuse illuminator (block **1018**) to illuminate. As described in various of the above-incorporated-by-reference patent applications, the ring **1020** can include individual banks of LEDs (or other illumination sources) that, in this example, are formed into quadrants—namely top/north **1022**, bottom/south **1024**, right/east **1026** and left/west **1028** (as viewed from outside, toward the reader front). These quadrants can be individually addressed by the processor. This allows the output of each quadrant to be varied so as to generate the desired effect on the object. This is particularly useful, where the reader may be disposed at a non-perpendicular angle to the object surface or the surface is non-flat. Various automatic adjustment processes can be included to efficiently cycle through various lighting arrangements among the quadrants to determine the arrangement/profile that achieves the best image. In this embodiment, the individual illumination sources (LEDs **1030**) are commercially available multi-color LEDs (red and green in this embodiment, denoted schematically by the split line down the middle of each LED **1030**), capable of projecting either of two colors in response to the processor **1010**. This can be useful, form an imaging standpoint, where a different color is to be provided

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for dark field and direct bright field. More significantly, the illumination ring's multicolor capability allows the light pipe (particularly the frosted end **820**) to project a highly visible, subject-adjacent indicator light in a plurality of colors.

FIG. **11** details generally the illumination of the light pipe **810** for the purpose of providing the user an indicator. In this example, the four quadrants **1110**, **1120**, **1130** and **1140** of the textured chamfered edge **820** are illuminated red (denoted by the encircled R's) by their appropriate banks of LEDs in the ring. The frosted surface in fact generates a bright, diffuse color strip that enhances viewing of the indicator. This indicator can be illuminated before, during or after image acquisition as a continuous or blinking signal. Blinks can be timed in the manner of Morse code to achieve a desired status message. It should be clear that providing a large, clearly visible indicator light at the distal end of the light pipe (near to the mark-where the user will have his or her attention focused) affords a highly effective indicator that does not distract the user from the subject at hand and that is visible whether the reader is placed in close proximity to the object surface or at a standoff therefrom. In fact, at standoff distance, the indicator itself projects a colored light onto the surface, further focusing the user's attention on the task at hand.

As shown in FIG. **12**, all light-pipe-end quadrants **1110**, **1120**, **1130**, **1140** are illuminated in green (denoted by the encircled G's). This can be a solid (continuously green) or blinking indicator. It can also blink alternatively with red (or another color) according to any predetermined pattern to provide a particular message.

As shown in FIG. **13**, the indicator is characterized by two (or more) simultaneous colors displayed by different quadrants (or other sections) of the light pipe edge. In this example, the top quadrant **1110** is red and the left quadrant **1140** is green. The opposed bottom and left quadrants **1120** and **1130**, respectively, may also be red and green. This pattern may blink, or alternate (e.g., red and green switch). Likewise, a unique rolling change of colors may occur in which each quadrant, in turn changes to a different color so that the color change appears to migrate around the perimeter. Any observable and desirable shift of colors is contemplated as an indicator according to this invention.

Reference is now made to FIG. **14**, which shows a variation of the above described reflector shape. As discussed above, the length and angle (A) of the conical diffuser **280** (typically less than 45 degrees with respect to the axis **270** in each quadrant) defines a remote, distal region **1410** between the interior wall of the diffuser **280** and the shield **250** that is small in volume and difficult for light from the reflector **1420** to fill adequately. The gap between the inner perimeter of the illumination board **214** and the interior wall of the diffuser further obscures transmission of light into this remote region **1410**. Thus, the reflecting surface **1422** of the reflector **1420** of this embodiment includes a plurality of steps **1424**, **1426**, **1428**, **1429** which are designed to direct specific portions of the reflected light (rays **1430**) from the LEDs **282** toward the various parts of the diffuser, including the remote regions **1410**. Not that, adjacent to the central window **1450** in the reflector (through which the imager views the subject), the plurality of small, angled steps **1429** formed in the cross section are particularly adapted to transmit rays **1430** from the light sources **282** to various points along the remote region **1410** for an optimized spread of light along the entire diffuser surface. The reflector **1420** in this embodiment also includes a textured surface and a white surface color for maximum diffusion. In alternate embodiments, a different surface color and surface finish can be employed. In this manner a more-

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uniform illumination of the complete diffuser surface is achieved, and the presence of light and dark spotting on the object is minimized.

While a stepped reflector **1420** is shown and described according to an embodiment of this invention, it is expressly contemplated that reflectors having a variety of surface cross-sectional profiles can be employed in alternate embodiments. Such reflectors should be adapted, using optical-focusing techniques, to spread light along the length of a tapered or conical diffuser of a shape generally contemplated herein so as to avoid undesirable spotting on localized regions of the surface of interest.

It is contemplated that a light pipe with a textured or frosted chamfered end according to the various embodiments of this invention can be produced by a variety of techniques including grit blasting or peening of a finished surface, a desirable construction technique entails molding of the light pipe from poured resin. The chamfered end is located near the bottom of the mold and the rearward end (adjacent to the illumination ring) is located at the top of the mold, at which location the finished pipe is ejected from the mold. The bottom of the mold is provided with a frosted or textured pattern so as to form this surface effect on the chamfered end of the finished pipe.

Referring to FIG. **15** which shows the cross section of the light pipe **244** the mold is constructed with a slight draft angle that tapers, so that the resulting light pipe **244** defines a pair of inner walls having a draft angle AD therebetween of approximately at least 2 degrees (each side being 1 degree relative to the axis **270**). Because the mold includes a frosted/textured surface, the draft angle is set at approximately 2 degrees, rather than the typical 1 degree for a smooth molded part. This 2-degree draft angle better overcomes the possible adhesion effects created between the finished pipe and the textured mold surface. This draft angle is employed where the texture is applied to the chamfered ends **230**. Note that the chamfered ends **230** each define therebetween an angle of approximately 70 degrees (each end being approximately 35 degrees relative to the axis **270**). It should be clear, however, that the techniques used for forming the light pipe and other components herein can vary within the scope of ordinary skill. Referring further to FIG. **15**, according to an alternate embodiment, the frosted or textured finish can be applied to the inner wall of the light pipe **244** at the end location **1520**. This location **1520** is exposed beyond the distal end of the diffuser **280** and shield **250** described above to allow unobstructed passage of dark field light (rays **510**). This causes the reflected dark field light to pass through a diffusive structure prior to striking the mark surface. Note that the textured surface can also be applied to the outer side (location **820**) in an embodiment of the invention. Alternatively, the textured surface may be selectively applied to only one of the inner location (**1520**) or outer location (**820**) as appropriate. It should be noted that, when applying texture to the interior wall at location **1520**, the draft angle AD (FIG. **14**) would typically be greater than 2 degrees. An appropriate draft angle can be determined by those of skill in the molding plastic parts.

According to the embodiments described above, the general cross sectional perimeter shape of the light pipe is rectangular (taken on a plane through axis **270**). For the purposes of this description, the term "rectangular" shall include minor deviations of the sides of the rectangle from a straight-line geometry. In other words, a rectangular shape herein may include, for example, curvilinear arcs as shown and described. In general, the term rectangular shall be defined generally as a set of linear or non-linear sides that intersect at each of four corners (that may be significantly rounded corners) that cause the approximate direction of two adjacent

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sides to vary by approximately ninety degrees. A highly generalized representation of a rectangular light pipe **1610** is shown in FIG. **16**. As described above, the sides **1620**, **1622**, **1624** and **1626** of the rectangular light pipe **1610** can be defined in terms of North (arrow N), South (arrow S), East (arrow E) and West (arrow W). Likewise, each edge of the distal, chamfered end can be correspondingly represented as EN (edge North), ES (edge South), EE (edge East) and EW (edge West). The length LNS between the North edge EN and South edge ES is shorter (in this embodiment) than the length LEW between the East edge EE and West edge EW (LNS<LEW). Note that in alternate embodiments the reverse may be true (LNS>LEW) or these measurements can be approximately equal.

Referring to FIGS. **17** and **18**, the chamfered edge along each side is disposed at the same fixed angle (approximately 55 degrees in this embodiment), generating dark field light rays that converge at point **1710** at an average fixed angle θ of approximately 32 degrees (representing half the chamfer angle along with an induced draft angle of 1 degree and further refraction as the light exits the pipe interior wall). Since the distance LNS is less than the distance LEW, the convergence distance of light DNS for the pair of opposing sides EN and ES is less than the convergence distance DEW of light from the pair of opposing sides EE and EW. Thus this arrangement affords a wider depth of field for the reader by providing two differing distance ranges of illumination for the mark. In an embodiment of this invention the approximate length NS is 3 cm, the approximate length EW is 4.5 cm. DNS is approximately 0.92 cm, while DEW is approximately 1.23 cm. Thus a desirable difference of more than 0.31 cm is provided for greater depth of field.

Besides providing a larger depth of field with two projection distances, the above-described rectangular light pipe shape presents several advantages over round light pipes and those of other regular, equilateral shapes. The rectangular shape more closely conforms to the conventional 4:3 horizontal-to-vertical ratio exhibited by commercially available sensors. The rectangular cross section yields a larger dark field range than provided by round pipes. It also allows for a lower-profile reader, in terms of overall height. Moreover, the use of discrete "sides" on the pipe makes it easier to control separate quadrants, as described above.

Note that, while the embodiments described herein generally contemplate somewhat polygonal shapes with adjacent sides connected by corners, it is expressly contemplated that continuously curving joints between "sides" can be provided. As such the terms "sides" and pair of opposing sides should be taken to include ellipses in which the opposing sides spanned by the major axis are greater in length than the opposing sides spanned by the minor axis. In this manner each set of sides generates an average convergence distance for dark field rays that is different, thereby producing the desired enhanced depth of field. To this end, FIG. **19** details an elliptical cross section light pipe **1910** that can be adapted for use with an embodiment of the invention (with appropriate reshaping of the illumination ring and diffuser, where applicable). The distal end of the light pipe **1910** terminates in a chamfered end **1920** having an angle and function as generally described herein. The edge of the chamfered end, in essence defines an opposing pair of North and South sides (**1930** and **1932**, respectively) and East and West sides (**1940** and **1942**, respectively), which are separated by distances that differ. In this case the distances are the minor axis MIA and the major axis MAA (respectively) of the ellipse. In this embodiment, the "sides" can be characterized as continuously running into each other with arbitrary boundaries or with "continuously

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curving corners." A variety of variations on this basic elliptical shape are expressly contemplated. In any case, the sides generate at least two discrete distances of ray convergence for a given fixed chamfer angle.

It should be clear from the above-described embodiments, that a reader having superior illumination and mark-reading capabilities is described herein. This reader alleviates many of the disadvantages encountered with prior art readers, and provided improved object-illumination, status-indication and overall durability.

The foregoing has been a detailed description of illustrative embodiments of the invention. Various modifications and additions can be made without departing from the spirit and scope thereof. For example, any of the various features described herein can be combined with some or all of the other features described herein according to alternate embodiments. Additionally, while a plurality of multicolor LEDs are provided, individual monochromatic LEDs each in a plurality of colors can be arranged adjacent to each other on the illumination ring in alternate embodiments. Likewise, while a ring divided into quadrants is shown, any acceptable division of the overall ring can be provided according to alternate embodiments. Certain parts of the overall ring can be made to work together with other parts according to embodiments hereof. For example, top and right may always work together or top and bottom may always work together. Likewise, additional ring colors, such as yellow can be employed to provide further types of indicators. Multi-colored illumination sources or a plurality of adjacent individual illumination sources (or combinations of individual and multi-colored sources) can be used to generate the desired seat of ring colors. Moreover, while a rectangular light pipe is shown and described, a greater range of depth of field may be obtained by providing a non-equilateral shape having more than four sides joined by corners (for example, an oblique hexagon). This invention contemplates polygonal light pipe cross sections having four or more sides (linear or curvilinear) joined at corners (that may be rounded). Finally, it is expressly contemplated that any of the processes or steps described herein can be implemented as hardware, software, including program instructions executing on a computer, or a combination of hardware and software. Accordingly, this description is meant to be taken only by way of example, and not to otherwise limit the scope of this invention.

We claim:

1. An illumination assembly for a mark reader comprising:
 - a passive light transmitter including an inner lumen through which at least a portion of a mark is detectable, the passive light transmitter having a proximal end and a distal end, the distal end comprising a chamfered surface, the chamfered surface having a diffusive surface texture;
 - at least one light element positioned adjacent the proximal end and adapted to transmit light into the proximal end, at least a portion of the transmitted light internally reflecting through the light transmitter to the chamfered surface and, at the chamfered surface, reflecting out of the light transmitter through an interior wall of the light transmitter facing the inner lumen as dark field illumination; and
 - at least a different portion of the transmitted light internally reflecting through the light transmitter to the chamfered surface and being refracted out of the light transmitter and through the diffusive surface texture of the chamfered surface as bright field illumination.

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2. The illumination assembly according to claim 1 wherein the light transmitter comprises a flattened ring configuration and positioned generally perpendicular to the first direction.

3. The illumination assembly according to claim 1 wherein the diffuser includes staggered clear portions and diffusive portions.

4. An illumination assembly for a mark reader comprising:
a passive light transmitter including an inner lumen through which at least a portion of a mark is detectable, the passive light transmitter having a proximal end and a distal end;

at least one forward projecting light element positioned adjacent the proximal end and adapted to transmit a first light in a first direction into the proximal end, at least a portion of the transmitted first light internally reflecting through the light transmitter to the distal end and exiting the light transmitter as dark field illumination; and

at least one rearward projecting light element positioned so as to transmit a second light in a second direction so that the second light exits the assembly as direct light onto at least a portion of the mark.

5. The illumination assembly according to claim 4 wherein the direct light exits the assembly as bright field illumination.

6. The illumination assembly according to claim 4 wherein the at least one rearward projecting light element is positioned so as to transmit the second light in the second direction to spread the second light toward a diffuser positioned within the inner lumen, the diffuser diffusing the second light so that the diffused second light exits the diffuser as a spread of diffuse light onto at least a portion of the mark.

7. An illumination assembly for a mark reader comprising:
a passive light transmitter including an inner lumen through which at least a portion of a mark is detectable, the passive light transmitter having a proximal end and a distal end;

at least one forward projecting light element positioned adjacent the proximal end and adapted to transmit a first light in a first direction into the proximal end, at least a portion of the transmitted first light internally reflecting through the light transmitter to the distal end and exiting the light transmitter as dark field illumination;

a tapered diffuser positioned within the inner lumen, the diffuser diffusing a second light so that the diffused second light exits the diffuser as diffuse light onto at least a portion of the mark; and

wherein at least one rearward projecting light element is positioned so as to transmit the second light in a second direction to spread the second light toward the diffuser positioned within the inner lumen, the diffuser diffusing the second light so that the diffused second light exits the diffuser as a diffuse light onto at least a portion of the mark.

8. The illumination assembly according to claim 7 wherein the diffuse light exits the assembly as bright field illumination.

9. The illumination assembly according to claim 7 wherein the diffused second light exits the diffuser as a spread of direct, substantially uniform diffuse light onto the at least a portion of the mark.

10. The illumination assembly according to claim 7 wherein the rearward projecting light element transmits the second light in a second direction toward a reflector, the reflector adapted to spread the reflected second light toward the diffuser positioned within the inner lumen, the diffuser diffusing the reflected second light so that the diffused second light exits the diffuser as a spread of diffuse light onto the at least a portion of the mark.

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11. The illumination assembly according to claim 7 wherein the distal end comprises a chamfered surface, the chamfered surface having a diffusive surface texture.

12. The illumination assembly according to claim 11 wherein at least a different portion of the transmitted first light internally reflects through the light transmitter to the chamfered surface and is refracted out of the light transmitter by the diffusive surface texture of the chamfered surface as bright field illumination.

13. A mark reader comprising:

a light transmitter defined by a central axis and including at least a first light transmitter segment and a second light transmitter segment, the first light transmitter segment being spaced further from the central axis than the second light transmitter segment;

at least one light source adjacent a proximal end of the light transmitter;

the light transmitter further including a distal end, the distal end adapted to direct light from the at least one light source onto a surface as dark field illumination; and

the distal end of the first light transmitter segment directing the dark field illumination at a first convergence distance, and the distal end of the second light transmitter segment directing the dark field illumination at a second convergence distance, the second convergence distance being different than the first convergence distance.

14. The mark reader according to claim 13 wherein the light transmitter is constructed from polycarbonate.

15. The mark reader according to claim 13 wherein the light transmitter further defined by at least four adjacent sides including a first opposing pair of sides having a first spacing, and a second opposing pair of sides having a second spacing, the first spacing between the first opposing pair of sides having a length that is different than a length of the second spacing between the second opposing pair of sides.

16. The mark reader according to claim 15 wherein the distal end of the first opposing pair of sides directs the dark field illumination at a first convergence distance, and the distal end of the second opposing pair of sides directs the dark field illumination at a second convergence distance, the second convergence distance being different than the first convergence distance.

17. The mark reader according to claim 13 wherein the light transmitter distal end includes a chamfered surface.

18. The mark reader according to claim 17 wherein the chamfered surface of the light transmitter distal end includes a diffusive texture.

19. An illumination assembly for a mark reader comprising:

a passive light transmitter including an inner lumen through which at least a portion of a mark is detectable, the passive light transmitter having a proximal end and a distal end, the distal end comprising a chamfered surface, the chamfered surface having a diffusive surface texture;

at least one light element positioned adjacent the proximal end and adapted to transmit light into the proximal end, at least a portion of the transmitted light internally reflecting through the light transmitter to the chamfered surface and being refracted out of the light transmitter and through the diffusive surface texture of the chamfered surface as bright field illumination; and

a diffuser positioned within the inner lumen, the diffuser diffusing a different portion of the transmitted light so that the diffused transmitted light exits the diffuser as a spread of diffuse light onto at least a portion of the mark.

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20. The illumination assembly according to claim 19 wherein the diffused transmitted light exits the diffuser as diffuse bright field illumination.

21. The illumination assembly according to claim 19 wherein at least an additional different portion of the transmitted light internally reflects through the light transmitter to the chamfered surface and, at the chamfered surface, reflects out of the light transmitter through an interior wall of the light transmitter facing the inner lumen as dark field illumination.

22. A method of illuminating at least a portion of a mark to obtain an image, the method comprising:

providing a passive light transmitter including an inner lumen through which at least a portion of a mark is detectable, the passive light transmitter having a proximal end and a distal end, the distal end comprising a chamfered surface;

illuminating at least one light element positioned adjacent the proximal end;

transmitting light from the at least one light element into the proximal end, at least a portion of the transmitted light internally reflecting through the light transmitter to the chamfered surface and being refracted out of the light transmitter and through the chamfered surface to illuminate at least a portion of the mark with bright field illumination;

obtaining a first image of the at least a portion of the mark with the bright field illumination;

transmitting a different portion of the light from the at least one light element toward a diffuser, the diffuser diffus-

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ing the at least a different portion of the light so that the diffused light exits the diffuser to illuminate the at least a portion of the mark as diffuse light; and

obtaining a second image of the at least a portion of the mark with the diffuse light.

23. The method according to 22 wherein the diffused light exits the diffuser as diffuse bright field illumination.

24. The method according to 22 wherein the chamfered surface includes a diffusive surface texture.

25. The method according to 22 wherein the diffuser is positioned within the inner lumen.

26. The method according to 22 wherein the at least one light element includes at least a first light element for transmitting light into the proximal end, and at least a second light element for transmitting light toward the diffuser.

27. The method according to 22 further including internally reflecting at least a different portion of the transmitted light through the light transmitter to the chamfered surface and, at the chamfered surface, reflecting the different portion of the transmitted light out of the light transmitter through an interior wall of the light transmitter facing the inner lumen to illuminate the at least a portion of the mark with dark field illumination.

28. The method according to 27 further including obtaining a third image of the at least a portion of the mark with the dark field illumination.

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